Advanced Network Technologies

4G LTE

Dr. Wei Bao | Lecturer
School of Computer Science

THE UNIVERSITY OF SYDNEY

Insert Partner Logo
- Delete if not required

THE UNIVERSITY OF SYDNEY

4G/5G cellular networks

- *the* solution for wide-area mobile Internet
- widespread deployment/use:
  - more mobile-broadband-connected devices than fixed-broadband-connected devices (2019)!
  - 4G availability: 97% of time in Korea, 90% in US
- transmission rates up to 100's Mbps
- technical standards: 3rd Generation Partnership Project (3GPP)
  - wwww.3gpp.org
  - 4G: Long-Term Evolution (LTE) standard

4G/5G cellular networks

similarities to wired Internet

- edge/core distinction, but both below to same carrier
- global cellular network: a network of networks
- widespread use of protocols we've studied: HTTP, DNS, TCP, UDP, IP, etc.
- separation of data/control planes, SDN, tunneling
- interconnected to wired Internet

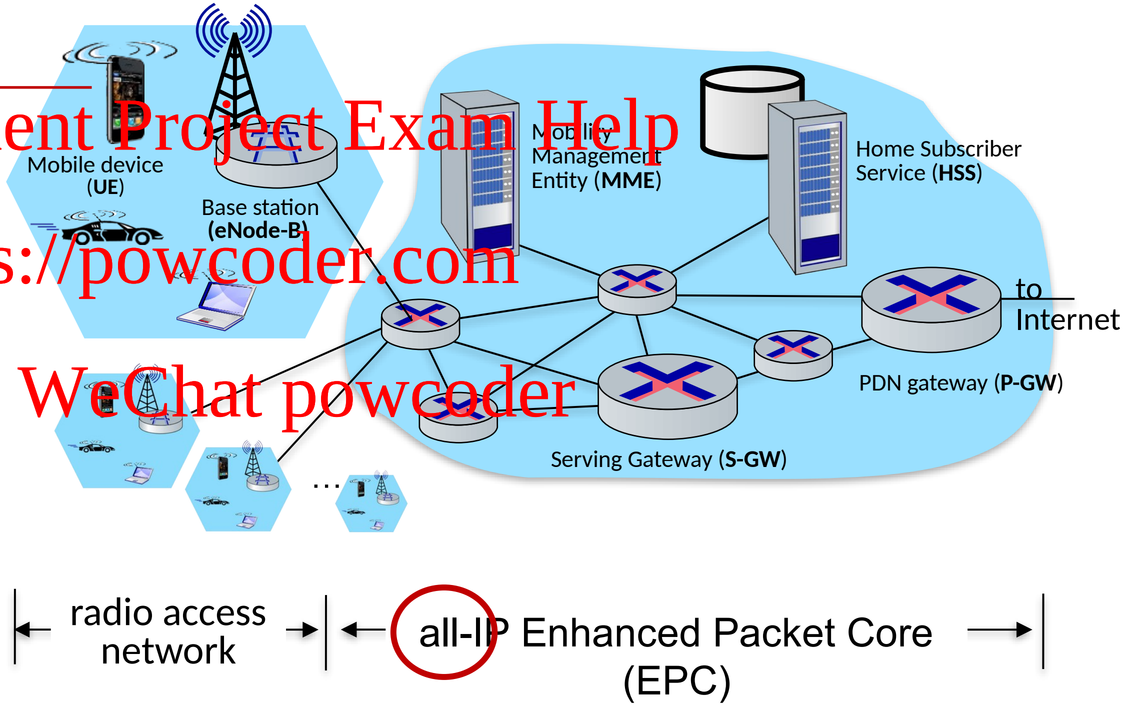
differences from wired Internet

- different wireless link layer
- mobility
- user "identity" (via SIM card)
  - subscriber identification module
- business model: users subscribe to a cellular provider
  - "home network" versus roaming on visited nets
  - global access, with authentication infrastructure, and inter-carrier settlement

Elements of 4G LTE architecture

Mobile device:

- smartphone, tablet, laptop, IoT, ... with 4G LTE radio
- 64-bit International Mobile Subscriber Identity (IMSI), stored on SIM (Subscriber Identity Module) card
- LTE jargon: User Equipment (UE)

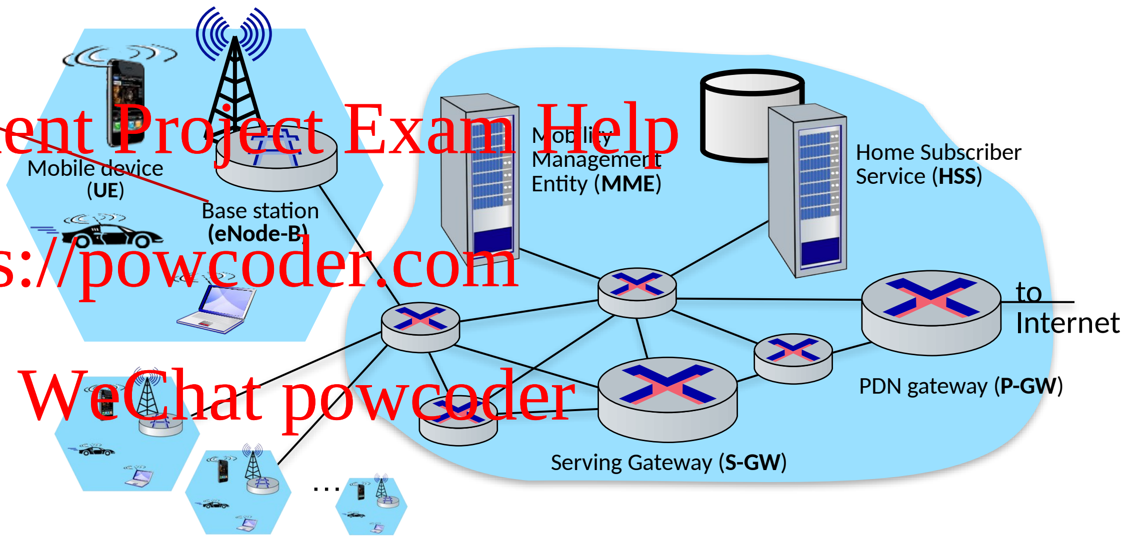


PDN: Packet Data Network

Elements of 4G LTE architecture

Base station:

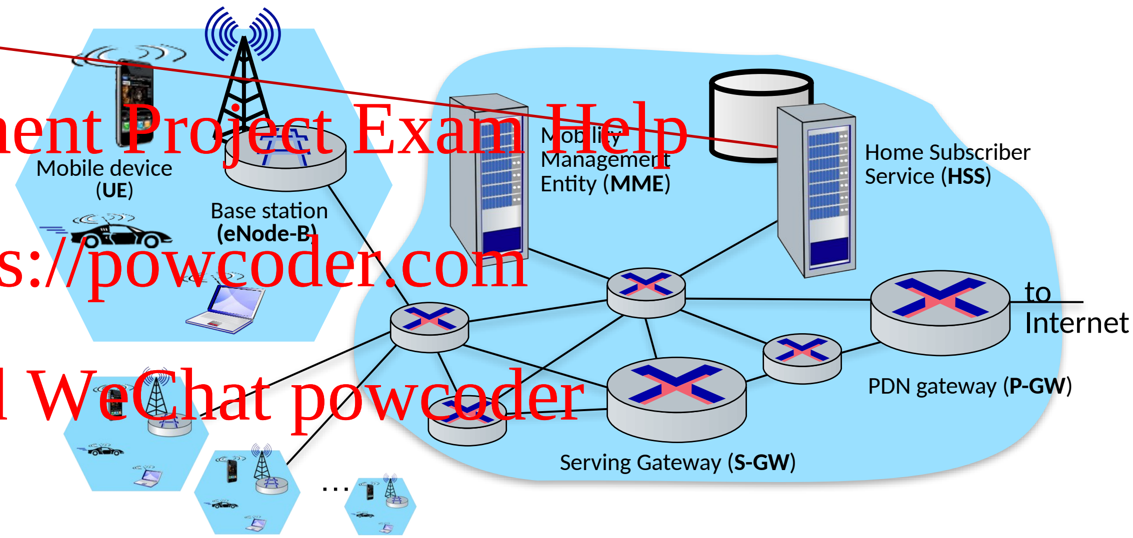
- at "edge" of carrier's network
- manages wireless radio resources, mobile devices in its coverage area ("cell")
- coordinates device authentication with other elements
- similar to WiFi AP but:
  - active role in user mobility
  - coordinates with nearly base stations to optimize radio use
- LTE jargon: eNode-B



Elements of 4G LTE architecture

Home Subscriber Service

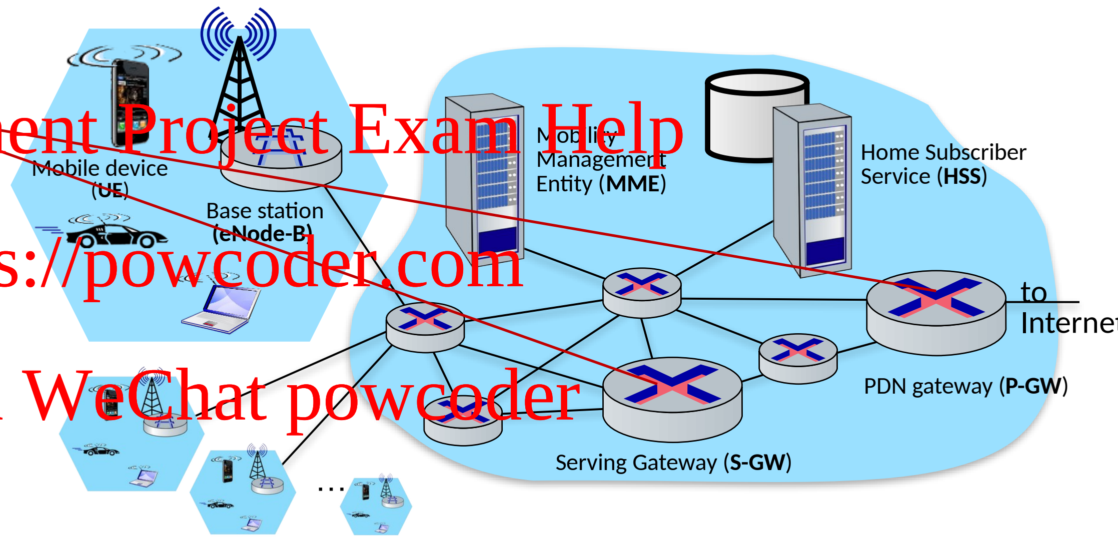
- stores info about mobile devices for which the HSS's network is their "home network"
- works with MME in device authentication



Elements of 4G LTE architecture

Serving Gateway (S-GW), PDN Gateway (P-GW)

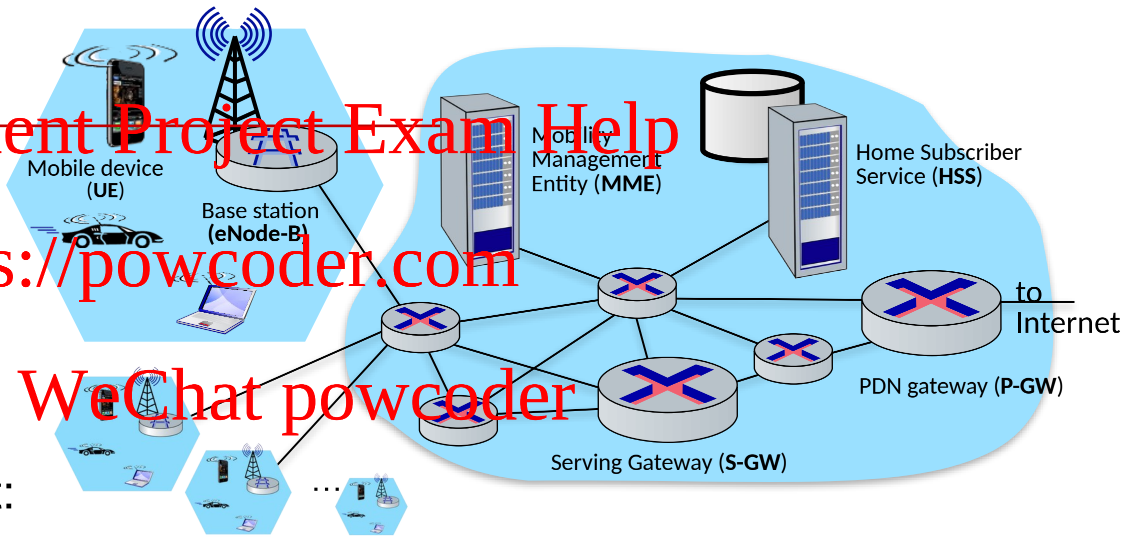
- lie on data path from mobile to/from Internet
- P-GW
  - gateway to mobile cellular network
  - Looks like other internet gateway router
  - provides NAT services
- other routers:
  - extensive use of tunneling



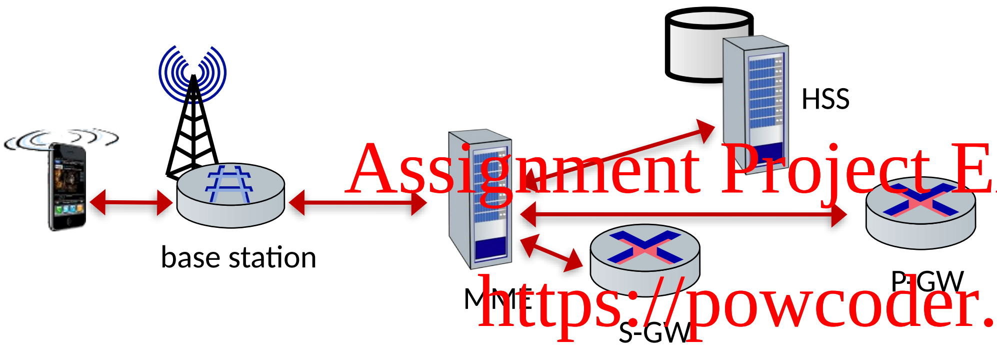
Elements of 4G LTE architecture

Mobility Management Entity

- device authentication (device-to-network, network-to-device) coordinated with mobile home network HSS
- mobile device management:
  - device handover between cells
  - tracking/paging device location
- path (tunneling) setup from mobile device to P-GW

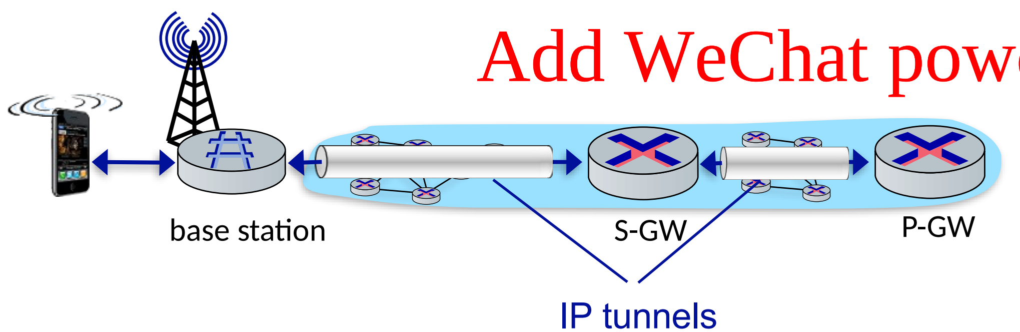


LTE: data plane control plane separation



control plane

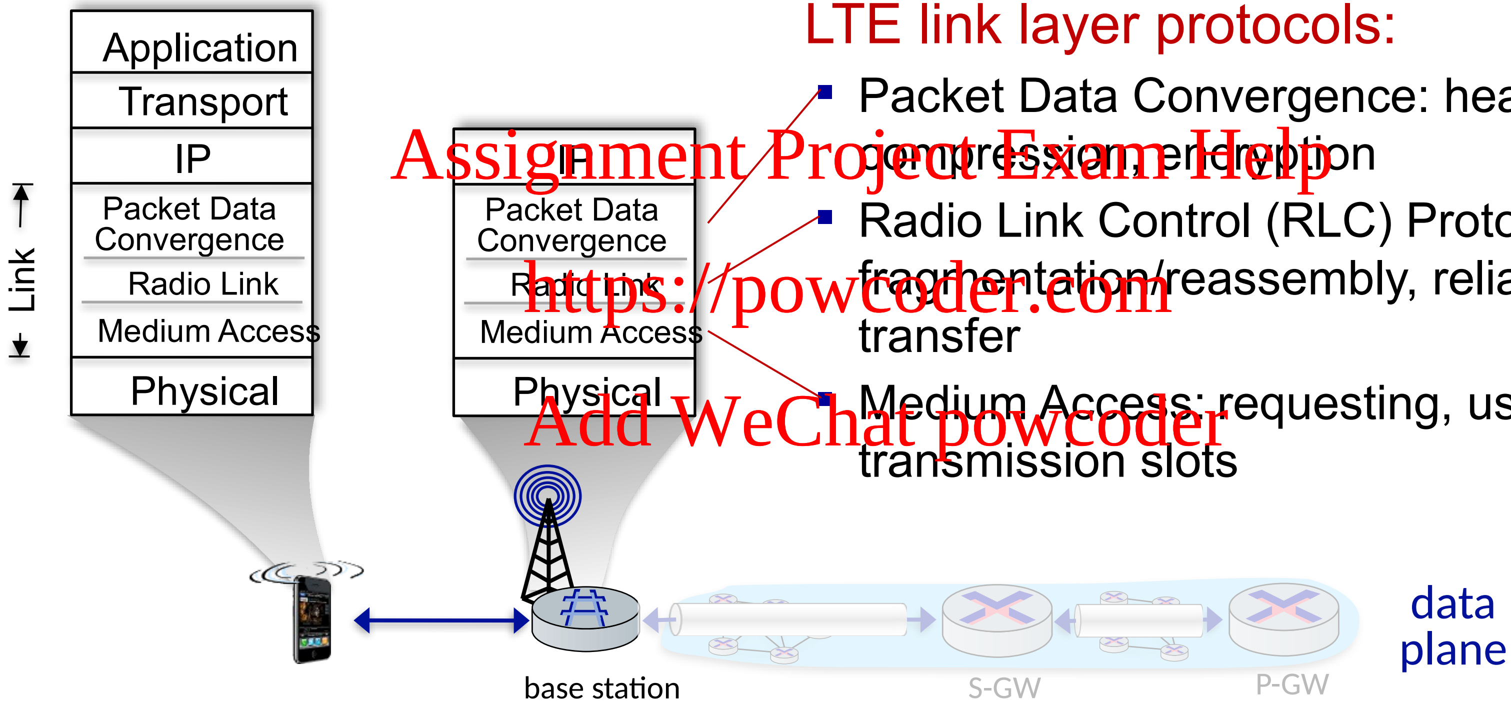
- new protocols for mobility management , security, authentication



data plane

- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

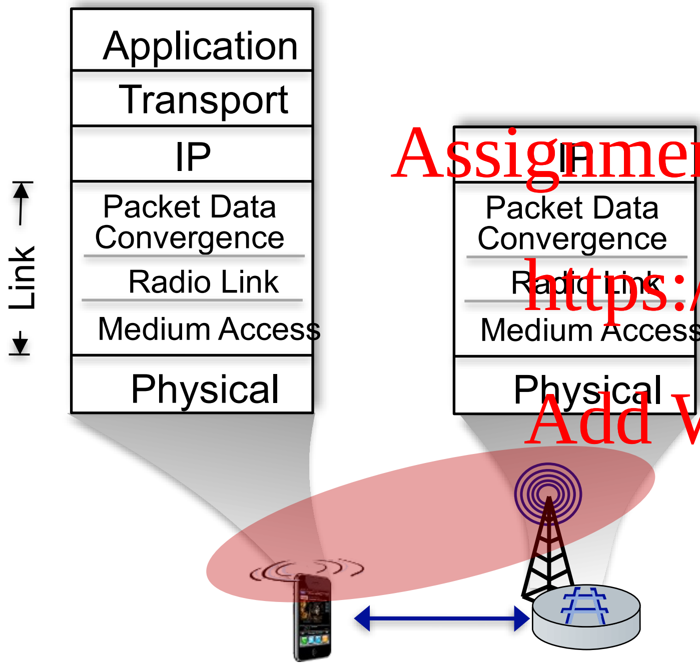
LTE data plane protocol stack: first hop



LTE link layer protocols:

- Packet Data Convergence: header compression, encryption
- Radio Link Control (RLC) Protocol: fragmentation/reassembly, reliable data transfer
- Medium Access: requesting, use of radio transmission slots

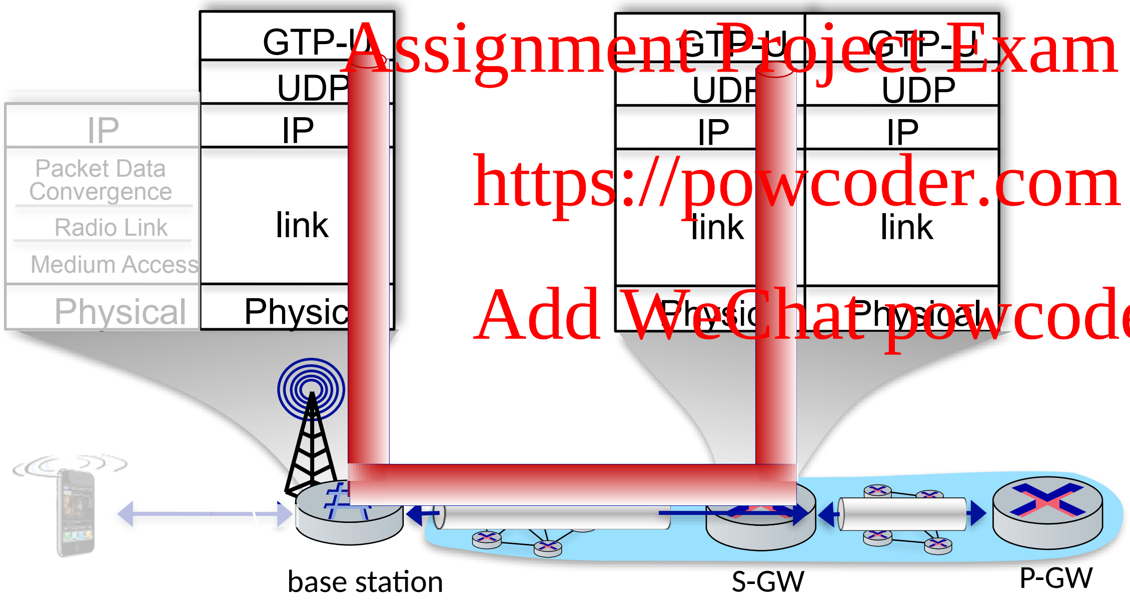
LTE data plane protocol stack: first hop



LTE radio access network:

- downstream channel: FDM, TDM within frequency channel (OFDM - orthogonal frequency division multiplexing)
  - “orthogonal”: minimal interference between channels
  - upstream: FDM, TDM similar to OFDM
- each active mobile device allocated two or more 0.5 ms time slots over 12 frequencies
  - scheduling algorithm not standardized – up to operator
  - 100’s Mbps per device possible

LTE data plane protocol stack: packet core



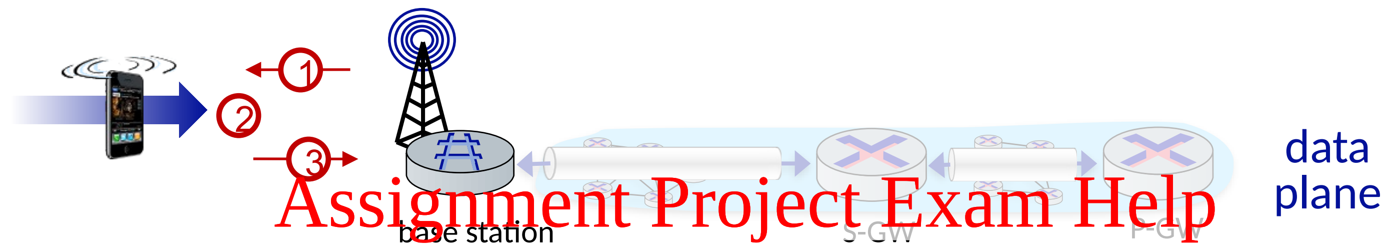
GTP-U: user data
GTP-C: control

tunneling:

- mobile datagram encapsulated using GPRS Tunneling Protocol (GTP), sent inside UDP datagram to S-GW
- S-GW re-tunnels datagrams to P-GW
- supporting mobility: only tunneling endpoints change when mobile user moves

THE UNIVERSITY OF SYDNEY

LTE data plane: associating with a BS



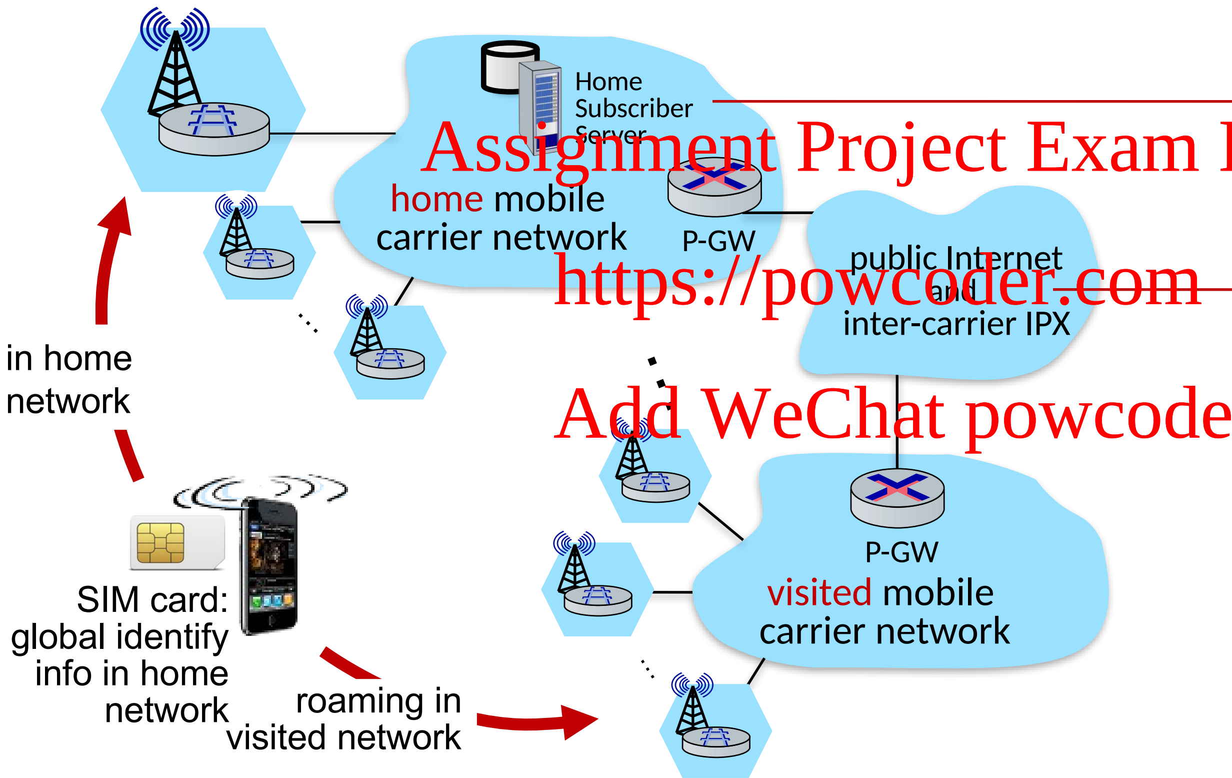
1. BS broadcasts primary synch signal every 5 ms on all frequencies
   - BSs from multiple carriers may be broadcasting synch signals
2. mobile finds a primary synch signal, then locates 2nd synch signal on this freq.
   - mobile then finds info broadcast by BS: channel bandwidth, configurations; BS's cellular carrier info
   - mobile may get info from multiple base stations, multiple cellular networks
3. mobile selects which BS to associate with (*e.g.,* preference for home carrier)
4. more steps still needed to authenticate, establish state, set up data plane

LTE mobiles: sleep modes

as in WiFi, Bluetooth: LTE mobile may put radio to "sleep" to conserve battery:

- light sleep: after 100's msec of inactivity
  - wake up periodically (100's msec) to check for downstream transmissions
- deep sleep: after 5-10 secs of inactivity
  - mobile may change cells while deep sleeping – need to re-establish association

Global cellular network: a network of IP networks



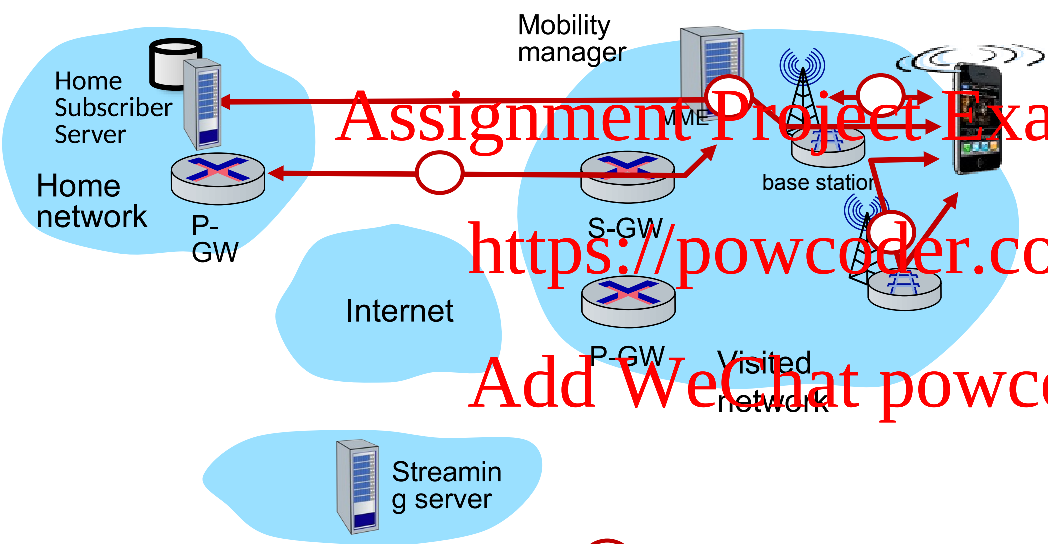
home network HSS:

- identify & services info, while in home network and roaming

all IP:

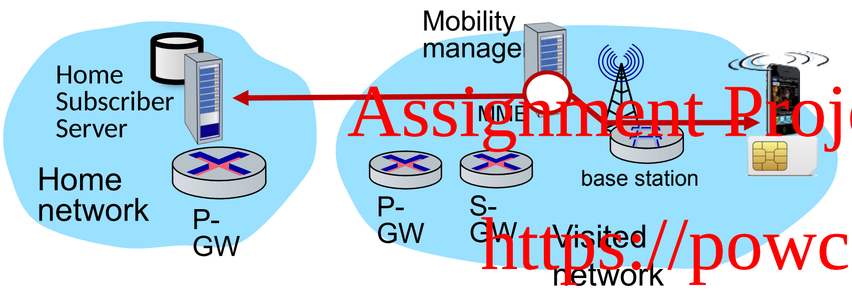
- carriers interconnect with each other, and public internet at exchange points
- legacy 2G, 3G: not all IP, handled otherwise

Mobility in 4G networks: major mobility tasks



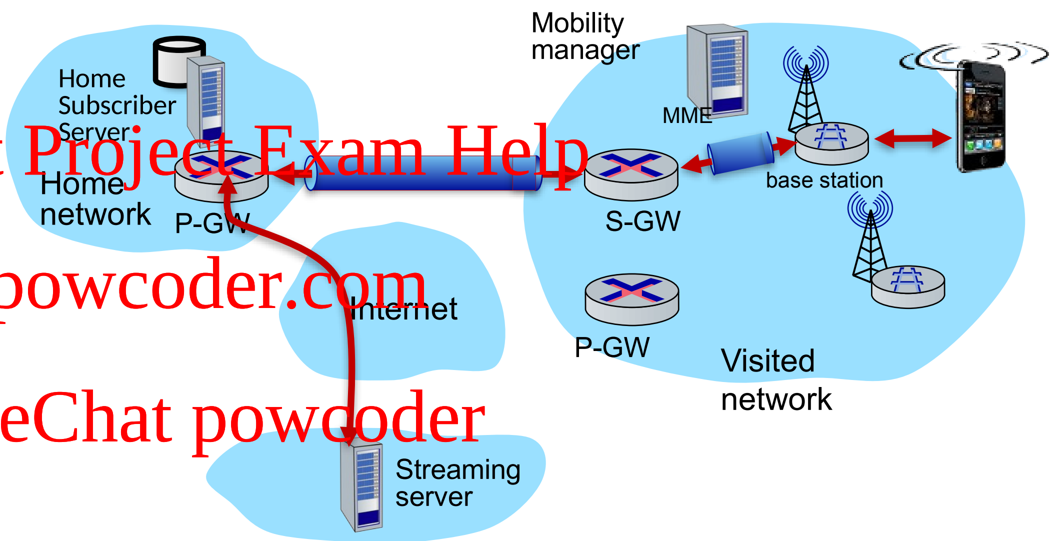
1. base station association:
   - covered earlier
   - mobile provides IMSI – identifying itself, home network
2. control-plane configuration:
   - MME, home HSS establish control-plane state - mobile is in visited network
3. data-plane configuration:
   - MME configures forwarding tunnels for mobile
   - visited, home network establish tunnels from home P-GW to mobile
4. mobile handover:
   - mobile device changes its point of attachment to visited network

Configuring LTE control-plane elements



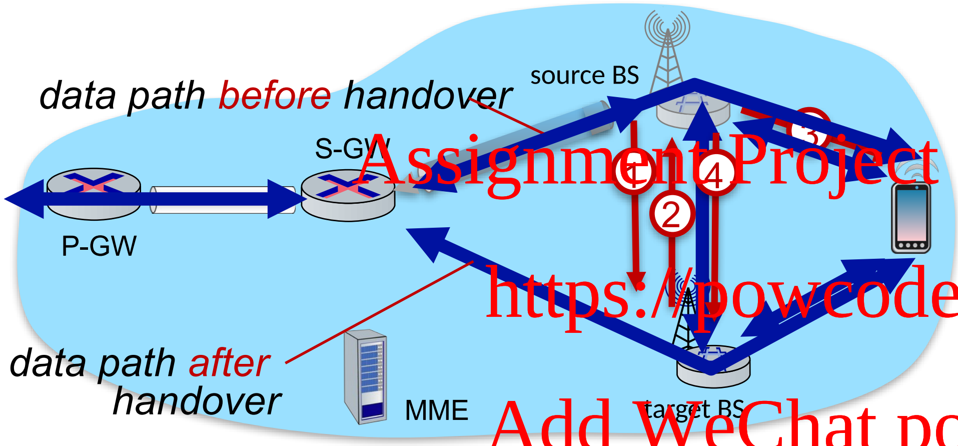
- Mobile communicates with local MME via BS control-plane channel
- MME uses mobile's IMSI info to contact mobile's home HSS
  - retrieve authentication, encryption, network service information
  - home HHS knows mobile now resident in visited network
- BS, mobile select parameters for BS-mobile data-plane radio channel

Configuring data-plane tunnels for mobile



- **S-GW to BS tunnel**: when mobile changes base stations, simply change endpoint IP address of tunnel
- **S-GW to home P-GW tunnel**: implementation of indirect routing
  - **tunneling via GTP** (GPRS tunneling protocol): mobile's datagram to streaming server encapsulated using GTP inside UDP, inside datagram

Handover between BSs in same cellular network



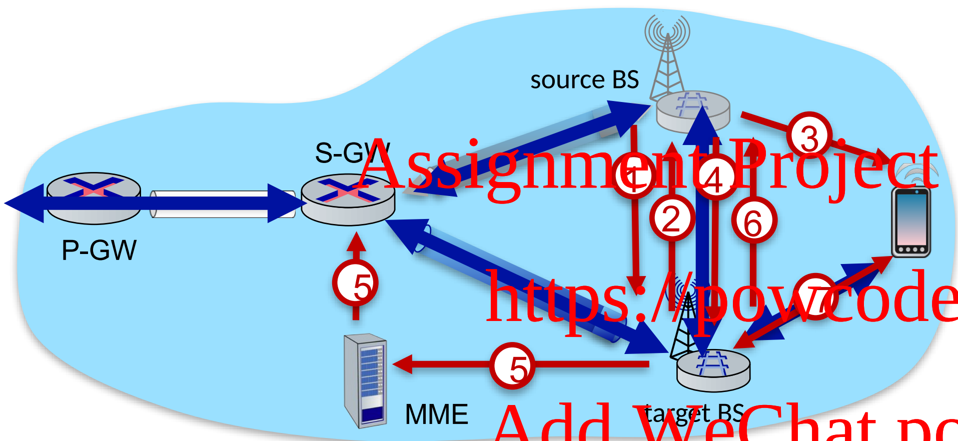
1 current (source) BS selects target BS, sends *Handover Request message* to target BS

2 target BS pre-allocates radio time slots, responds with HR ACK with info for mobile

3 source BS informs mobile of new BS
- mobile can now send via new BS - handover *looks* complete to mobile

4 source BS stops sending datagrams to mobile, instead forwards to new BS (who forwards to mobile over radio channel)

Handover between BSs in same cellular network



5 target BS informs MME that it is new BS for mobile
- MME instructs S-GW to change tunnel endpoint to be (new) target BS

6 target BS ACKs back to source BS: handover complete, source BS can release resources

7 mobile's datagrams now flow through new tunnel from target BS to S-GW

On to 5G!

- goal: 10x increase in peak bitrate, 10x decrease in latency, 100x increase in traffic capacity over 4G
- 5G NR (new radio):
  - two frequency bands: FR1 (450 MHz–6 GHz) and FR2 (24 GHz–52 GHz): millimeter wave frequencies
  - not backwards-compatible with 4G
  - MIMO: multiple directional antennae
- millimeter wave frequencies: much higher data rates, but over shorter distances
  - pico-cells: cells diameters: 10-100 m
  - massive, dense deployment of new base stations required

Advanced Network Technologies

Mobile Network Analysis, Erlang B, Erlang C

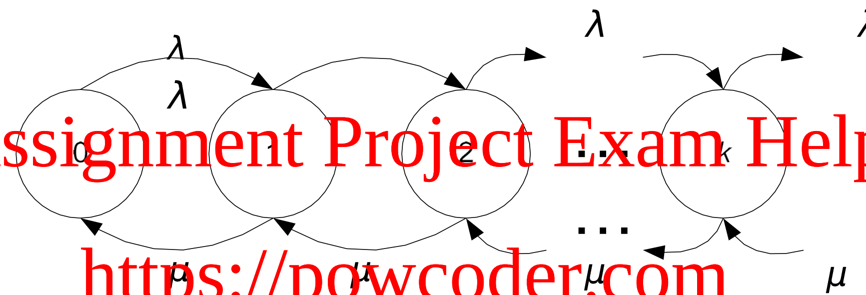
Dr. Wei Bao | Lecturer
School of Computer Science

THE UNIVERSITY OF SYDNEY

Insert Partner Logo
- Delete if not required

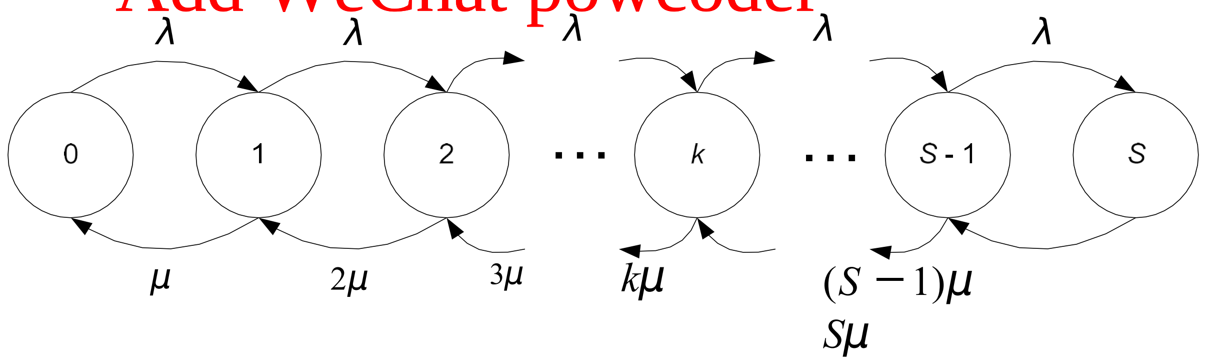
Review of M/M/1 and M/M/m/m Queue

M/M/1



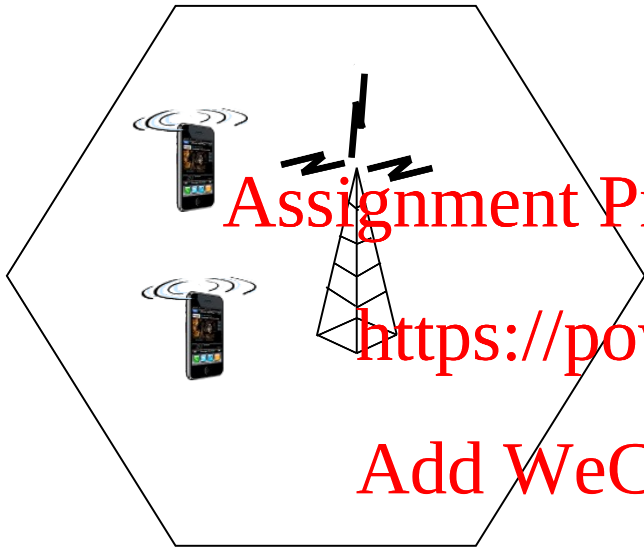
M/M/m/m

(m=S)



THE UNIVERSITY OF SYDNEY

M/M/m/m Queue Model

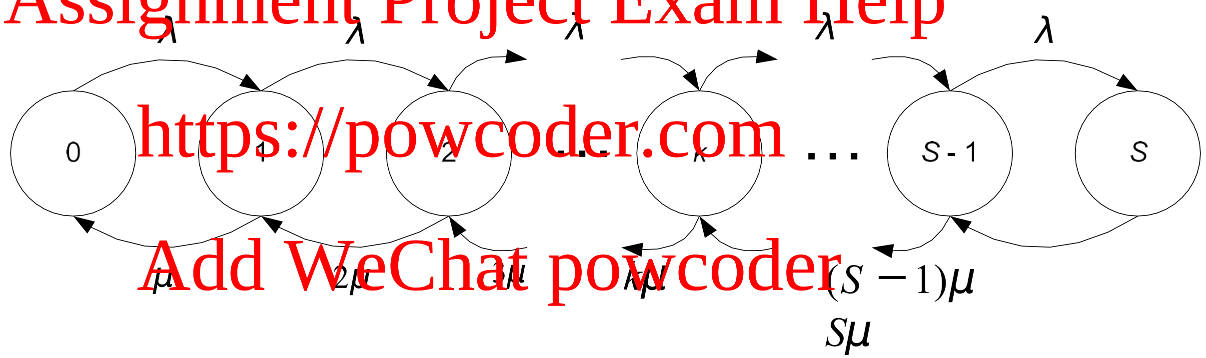


- The cell can serve *S* users (S channels)
- User arrival follows a Poisson process (arrival rate λ)
- User will use the channel for *t*, where *t* follows exponential distribution (mean $1/\mu$)
- *t* is called “channel holding time”
- New arrivals will be dropped if all channels are occupied.

M/M/m/m Queue Model

M/M/m/m

(m=S)



Q: What is the probability if a new arrival is dropped?

P_S

Poisson arrival sees time average.

Erlang B formula

Erlang B formula, or Erlang loss formula, the formula for the **blocking probability**

$$P_S = \frac{(\lambda/\mu)^S / S!}{\sum_{n=0}^{S} (\lambda/\mu)^n / n!} \quad \text{Erlang B Formula}$$

P_S is also called grade of service (GOS).

Erlang B formula for system design

Q1 (Performance Evaluation): Given traffic load (λ / μ), number of channels (S), calculate blocking probability P_S

A: Directly apply Erlang B formula

Q2 (Traffic Shaping) : Given blocking probability, number of channels, calculate max traffic load

A: Solve the value of λ / μ by Erlang B formula; using Erlang table/chart.

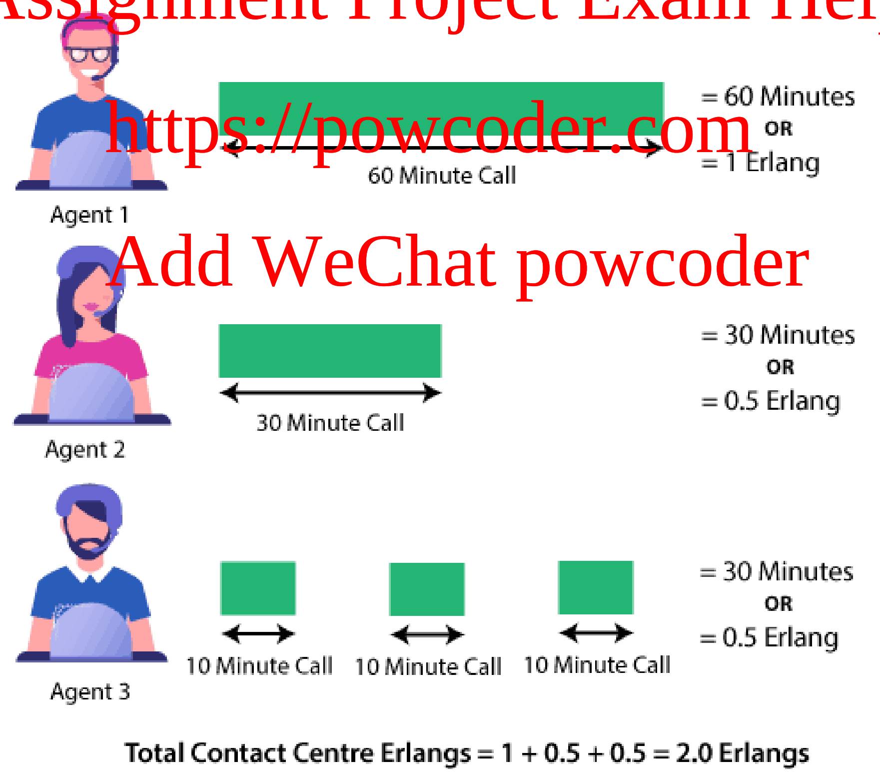
Q3 (Channel Reservation) : Given blocking probability, traffic load, calculate the number of channels needed

A: Solve the value of S by Erlang B formula; using Erlang table/chart.

Erlang

Erlang: a dimensionless unit used as a measure of offered load

The average number of concurrent calls measured over a time unit.



https://www.callcentrehelper.com/what-are-erlangs-154459.htm

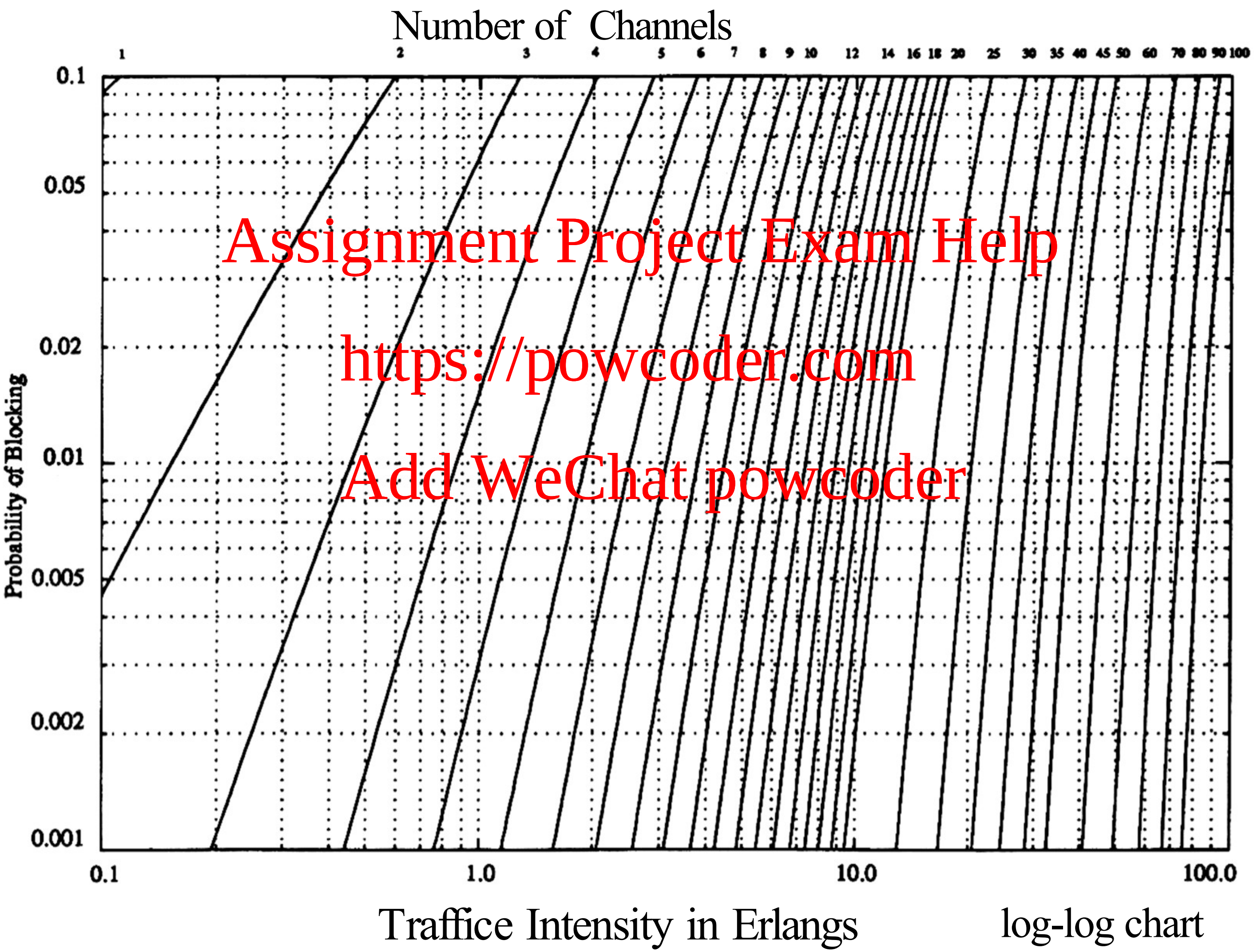
Erlang: In our model

λ: average number of arrivals per unit time.

$1/\mu$: average channel holding time.

Traffic load is λ/μ Erlang.

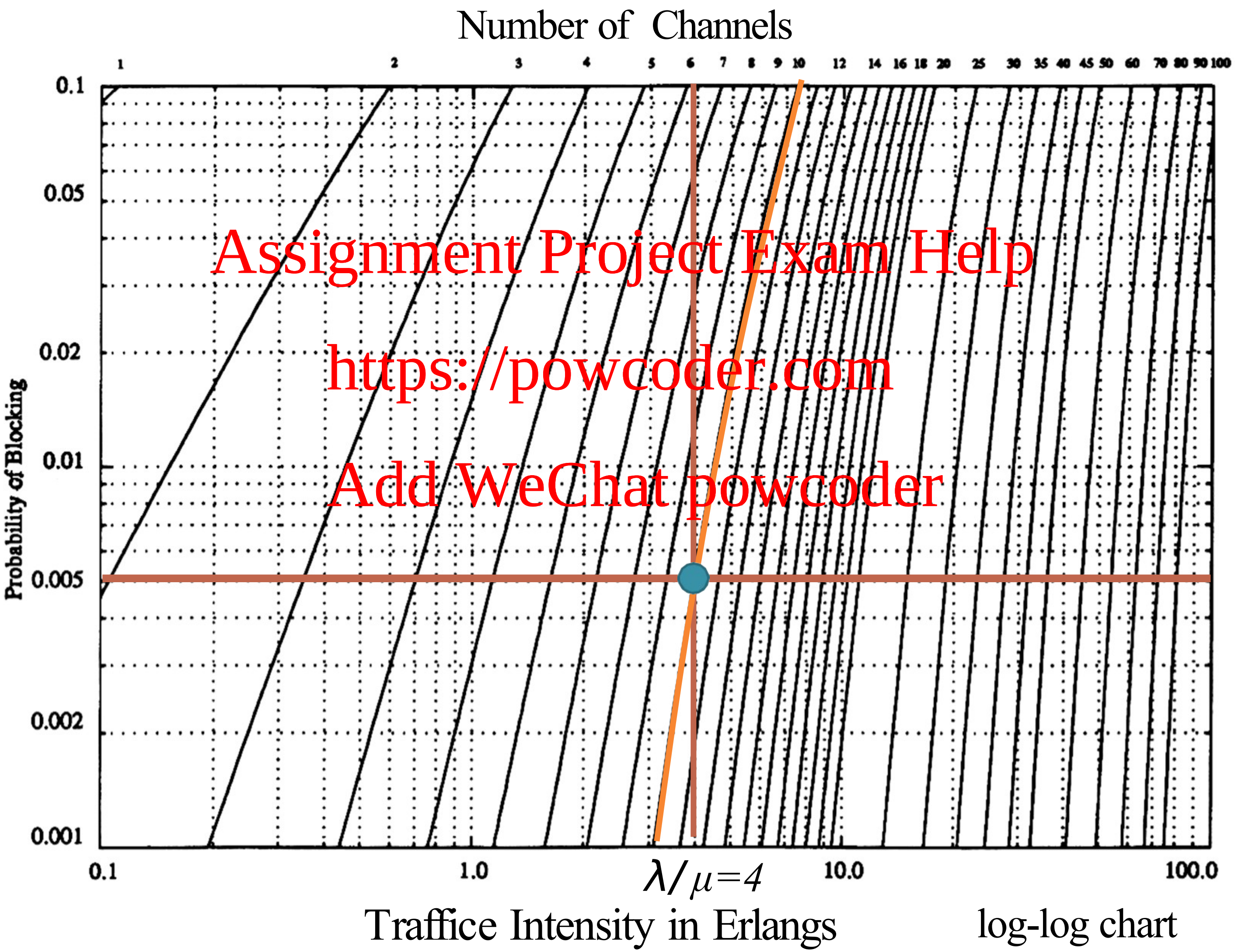
Erlang B chart



Example A

- Assume there are 10 channels.
- Assume each user uses the channel for 6 minutes (0.1 hour).
- What is the arrival rate can be supported for 0.5% blocking probability?

Example A


Number of Channels
1
2
3
4
5
6
7
8
9
10
12
14
16
18
20
25
30
35
40
45
50
60
70
80
90
100
Probability of Blocking
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.1
1.0
λ/μ=4
10.0
100.0
Traffice Intensity in Erlangs
log-log chart

Example A

$\lambda/\mu=4$

and $1/\mu = 0.1$ hour

$\lambda=40$ units/hour

Example B

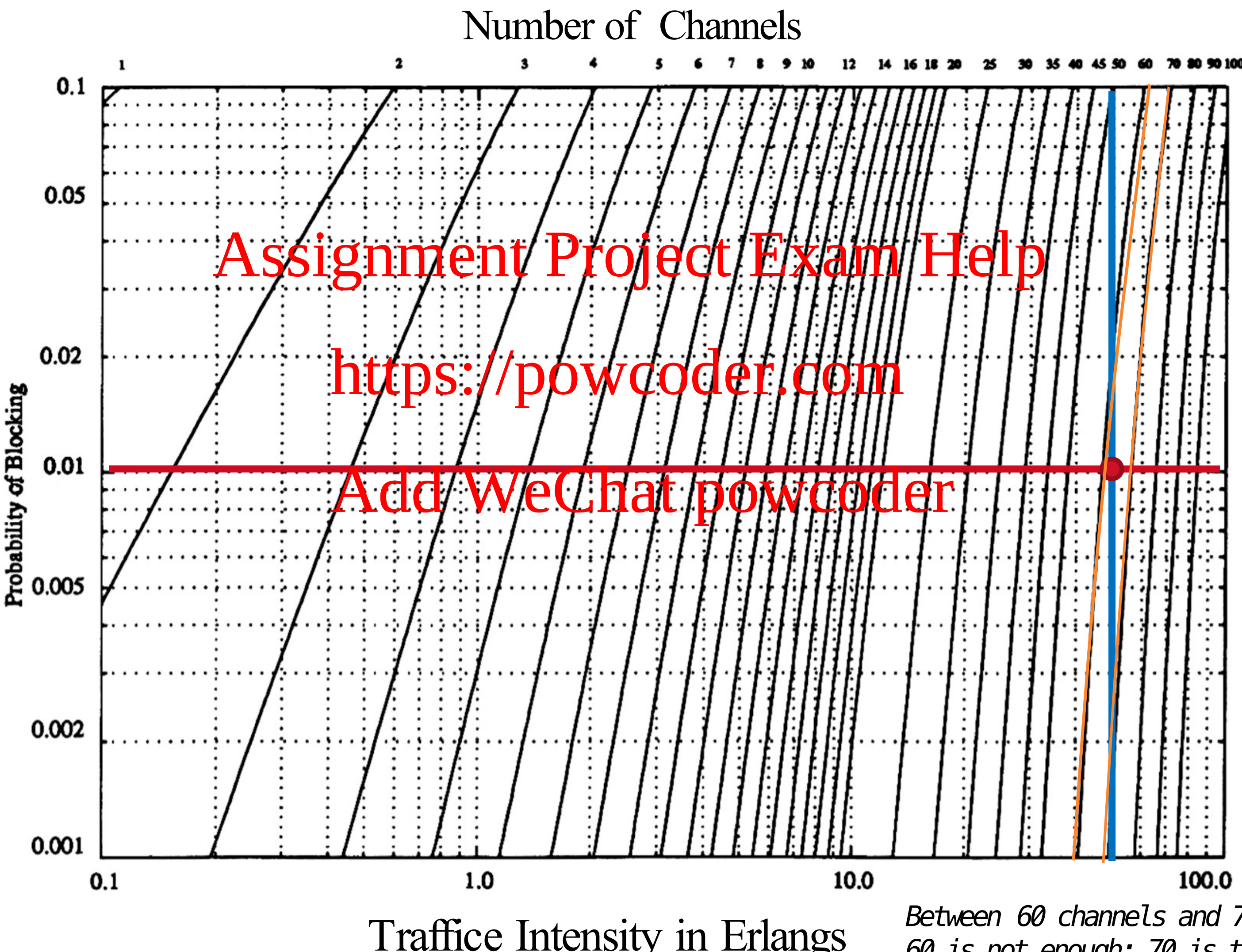
- Consider a base station
  - An average call lasts two minutes
  - 1500 calls per hour on average
  - the probability of blocking is to be no more than 1%.
- How many channels do we need?

λ=1500 units/hour

$1/\mu = 1/30$ hour

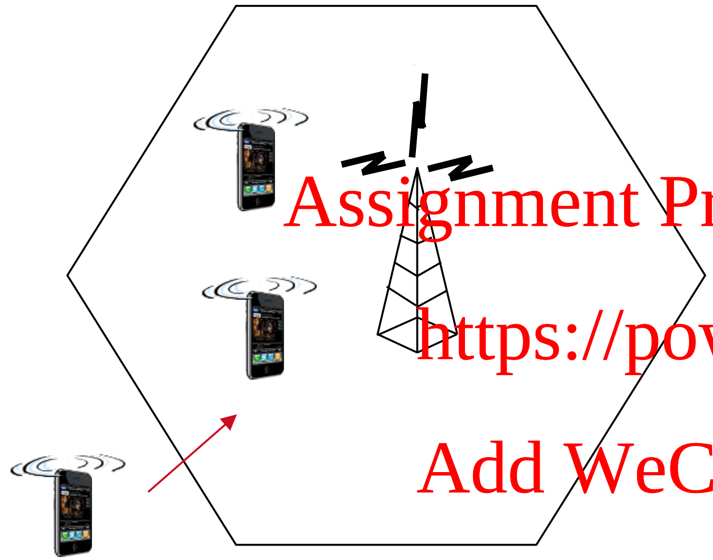
$\lambda/\mu = 50$ Erlang

Example B



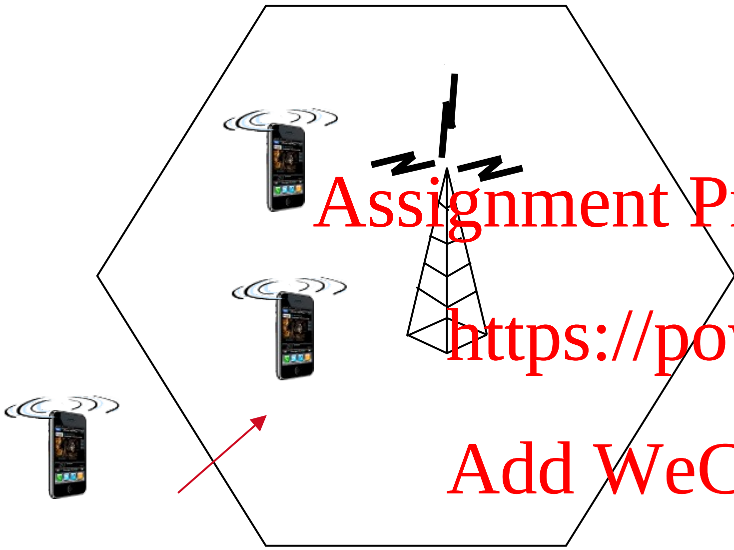
Between 60 channels and 70 channels; 60 is not enough; 70 is the number of channels needed.
(More accurate calculation is 64)

Queue Model with Handover



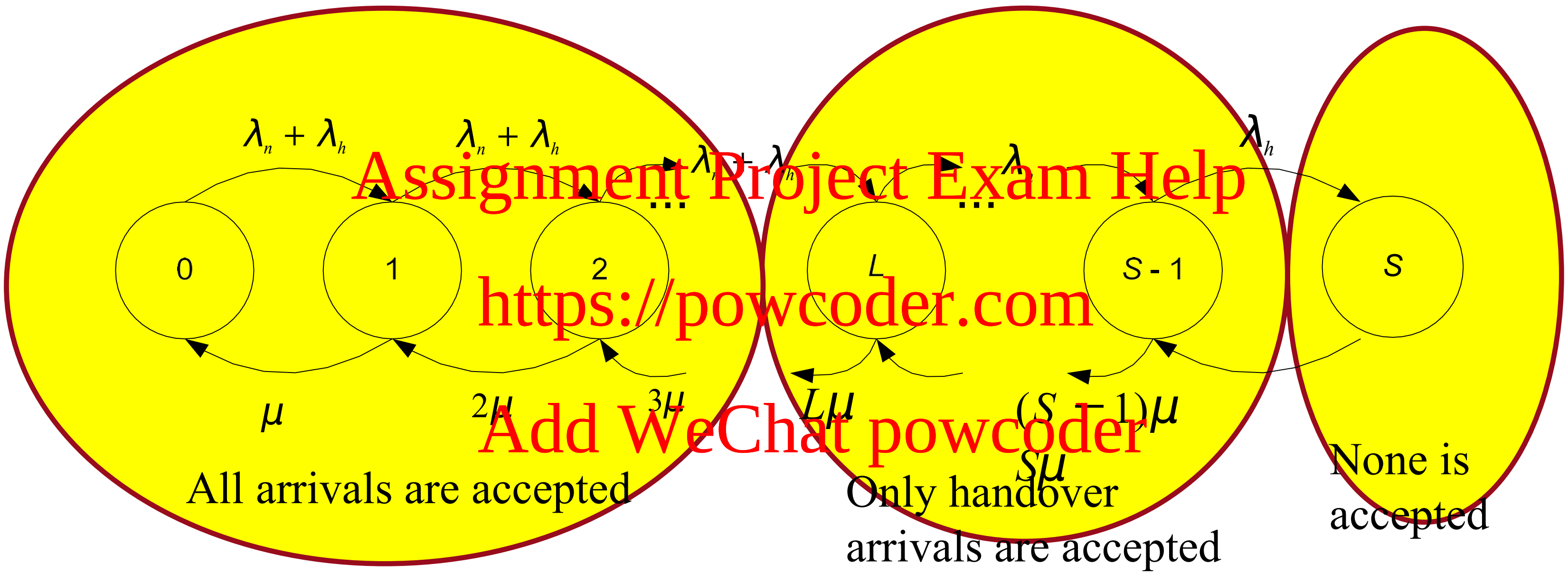
- The cell can serve *S* users (S channels)
- Intra-cell new arrival follows a Poisson process (arrival rate λ_n)
- Inter-cell handover arrival follows a Poisson process (arrival rate λ_h)
- User will use the channel for *t*, where *t* follows exponential distribution (mean $1/\mu$)
- S channels.

How to block/drop calls?



- Block intra-cell new arrival. Penalty
- Drop Inter-cell handover arrival. Higher penalty
- Guard channel approach!
- S-L guarded channels
- [0,L-1] active users, new arrivals and handover arrivals are accepted.
- [L, S-1] active users, new arrivals are blocked, handover arrivals are accepted.
- S or more active users. new arrivals are blocked, handover arrivals are dropped.

Guard channel approach



New arrival blocking probability $P_b = P_L + P_{L+1} + \ldots + P_S$

Handover dropping probability $P_d = P_S$

$$P_i = \frac{((\lambda_n + \lambda_h)/\mu)^i / i!}{\sum_{n=0}^{L} ((\lambda_n + \lambda_h)/\mu)^n / n! + \sum_{n=L+1}^{S} ((\lambda_n + \lambda_h)/\mu)^L (\lambda_h/\mu)^{n-L} / n!} \qquad 0 \le i \le L$$

Calculate the $L < i \le S$ case by yourself

Assignment Project Exam Help

https://powcoder.com

Add WeChat powcoder

System design problem

Q1 (Performance Evaluation): Given traffic load (λ_n , λ_h , and μ), number of channels (L and S), calculate probabilities (P_b and P_d)

Q2 (Traffic Shaping) : Given required probabilities (P_b and P_d) number of channels (L and S), calculate the traffic load

Q3 (Channel Reservation) : Given required probabilities (P_b and P_d) , traffic load, calculate the number of channels needed

S is also given, calculate the optimal L

Erlang C

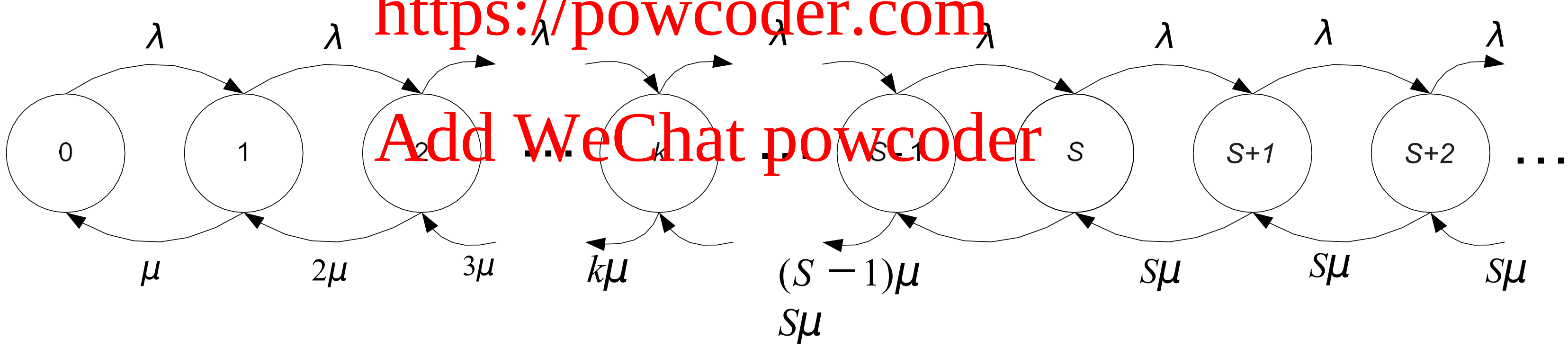
An arriving unit will need to wait if all servers are busy (it is not blocked)

Examples: Call centers

M/M/m queue

M/M/m

(m=S)

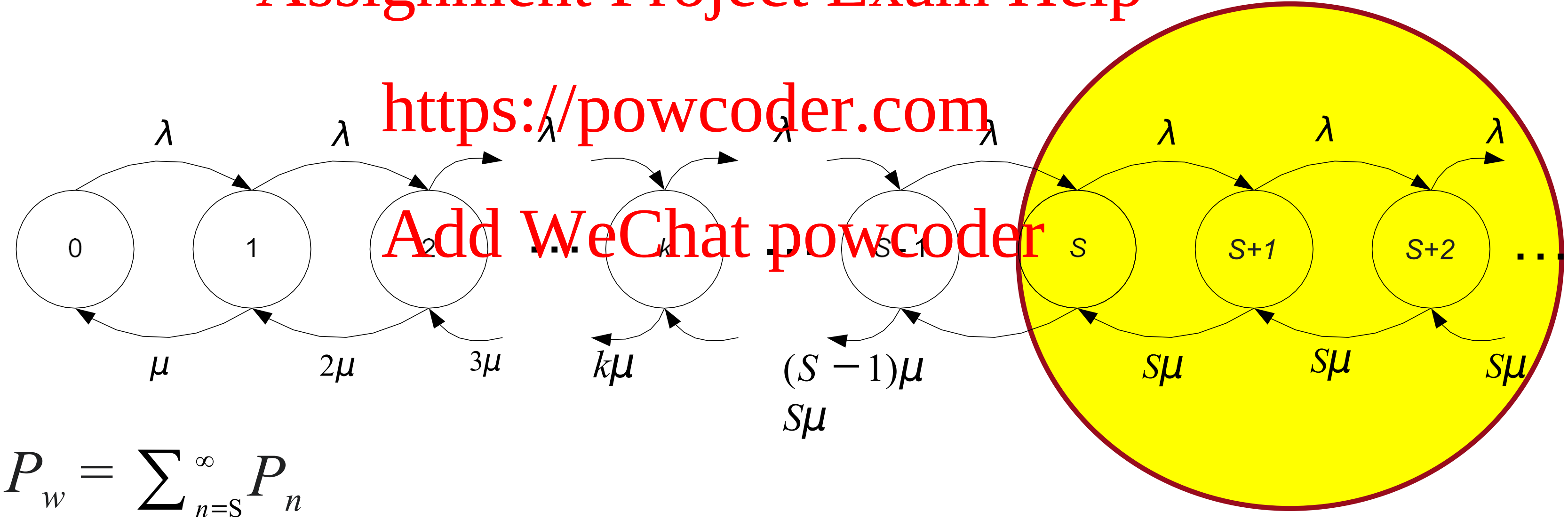


Erlang C

P_w: The probability that a new arrival has to wait (cannot be served immediately).

M/M/m

(m=S)



$$P_w = \sum_{n=S}^{\infty} P_n$$

Erlang C

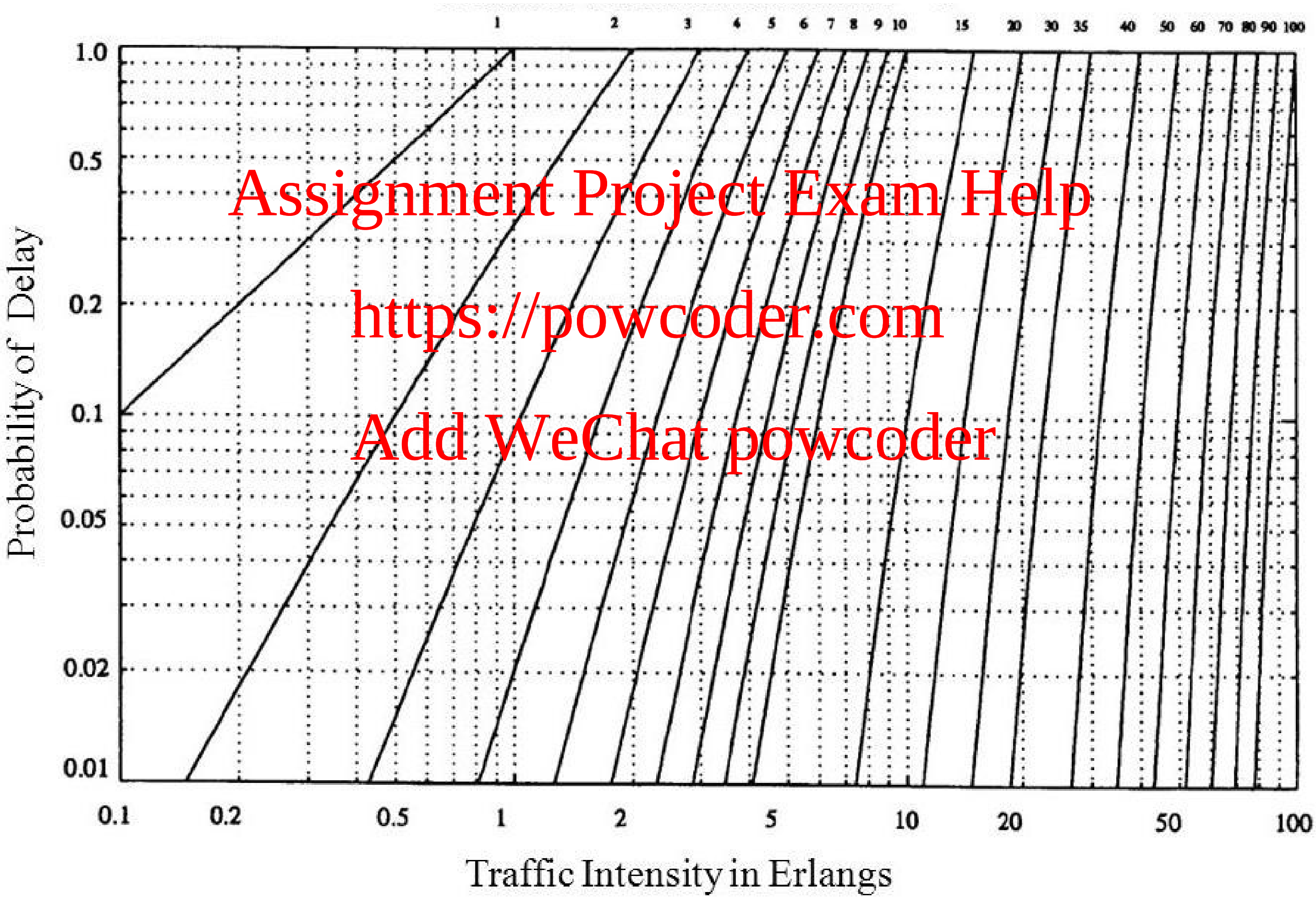
P_w: The probability that a new arrival has to wait (cannot be served immediately). Erlang C formula

$$P_w = \sum_{n=S}^{\infty} P_n$$

$$P_w = \frac{\frac{(\lambda/\mu)^S}{S!}\frac{S}{S-\lambda/\mu}}{\sum_{n=0}^{S-1}\frac{(\lambda/\mu)^n}{n!}+\frac{(\lambda/\mu)^S}{S!}\frac{S}{S-\lambda/\mu}}$$

P_w is grade of service (GOS).

Erlang C Chart



Advanced Network Technologies

Mobile Network Analysis, Bit Error Detection and Correction

Dr. Wei Bao | Lecturer
School of Computer Science

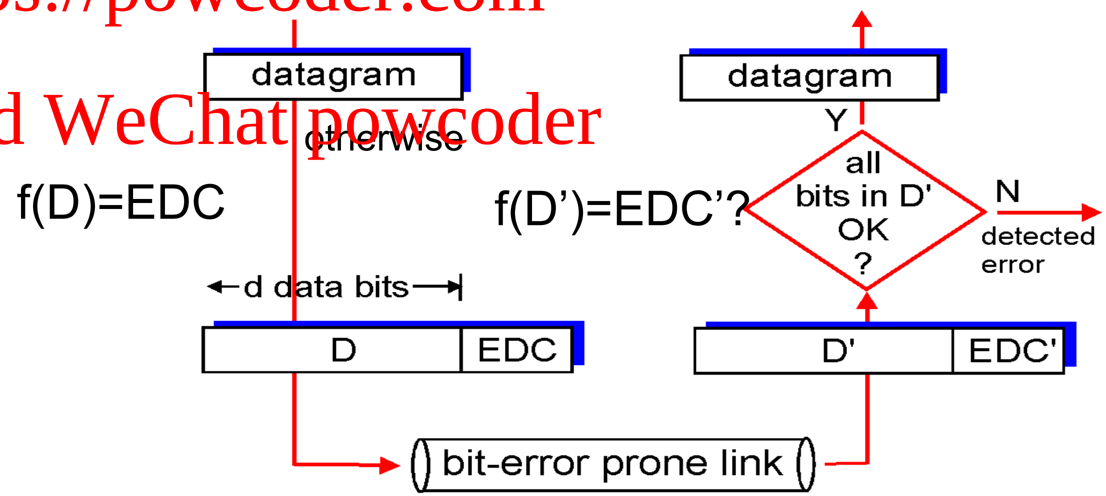
THE UNIVERSITY OF SYDNEY

Insert Partner Logo
- Delete if not required

Bit Error Detection and Recovery

EDC= Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include header fields

- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction



Modulo 2 operation

- Binary, modulo 2 domain
- addition, subtraction
  - 1+1=0, 1-1=0,
  - 1+0=1, 1-0=1
  - 0+1=1, 0-1=1
  - 0+0=0, 0-0=0
- "-", "+", are equivalent to, XOR, $\oplus$
- 11+11=00: no carry over
- Multiplication
  - $11*100=11*2^2=1100$ (left shift 2 bits)
  - 11*11=11*10+11*1=110+11=101

Parity Checking

Single Bit Parity:

Detect single bit errors

d data bits parity bit
110100 1

odd number of ‘1’s -> 1

even number of ‘1’s -> 0

total number of ‘1’s -> even

Parity Checking

Bit Check in Matrix format

identity submatrix | parity submatrix

$$\begin{bmatrix} c_0 & c_1 & c_2 \end{bmatrix} \left[\begin{array}{ccc|c} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \end{array}\right] = \begin{bmatrix} c_0 & c_1 & c_2 & c_0 + c_1 + c_2 \end{bmatrix}$$

dataword | generator matrix | codeword

Linear Block Code: Generalized Parity Check

Bit Check in Matrix format

identity submatrix parity submatrix

$$\begin{bmatrix} c_0 & c_1 & c_2 \end{bmatrix} \left[\begin{array}{ccc|cccc} 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 \end{array}\right] = \begin{bmatrix} c_0 & c_1 & c_1 & c_0+c_2 & c_0+c_1+c_2 & c_0+c_1 & c_1+c_2 \end{bmatrix}$$

dataword generator matrix codeword

dG=c

1*k vector k*n matrix 1*n vector

Linear Block Code: Generalized Parity Check

- k data bits
- n-k parity bits
- code rate: k/n

Linear Block Code: Decoding

paritycheck matrix **H**

Transpose of parity matrix

Identity submatrix

$$\begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 \end{bmatrix}$$

$GH^T=0$

Linear Block Code: Decoding

$$\begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$cH^T = dGH^T = 0$

Not 0? Error detected.